Biogas Potential of OFMSW through an Indirect Method

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Abstract

The usual tests for measuring the anaerobic biogas potential (ABP) of the Organic Fraction of Municipal Solid Waste (OFMSW) are reliable, but not practicable as a routine analysis. These types of analysis are expensive and time-consuming, requiring 21 (partial biogas production) to 100 days (total biogas production). Moreover, the operators of anaerobic digestion plants have often to choose which biomasses to use, depending on their digestibility and economical convenience. These matrices delivered daily to the plants, are heterogeneous especially with regard to the content of the biodegradable fraction, responsible for the potential production of biogas. In such a context, rapid methods toassess potential biogas productions are needed for helping operators in their choices. In order to contribute to solution tothese problems, in this work the Dynamic Respiration Index (DRI) was used to predict the anaerobic biogas potential. In this way, it is possible to know the ABP value in a short period of time (1–4 days). Two dynamic respirometric approaches were considered: the main difference between them is the temperature control (kept steady in one case, uncontrolled in the other one). In particular, DRI_{24} is determinated as the average integral over a period of 24 hours during the peak of maximum consumption in terms of oxygen. DRI_{24} is less affected by any oxygen consumption peak of limited duration. For these reasons, it wasrecommended to use its value to determinate the Potential Production of Biogas.A literature equation which determines the ABP from the value of DRI was modified in order to take advantage of the characteristics of the respirometric method with controlled temperature. About 130 Nm^3/t of food waste was assessed for the studied area, thanks to this method. In this way, it was demonstrated that the plant operators can adopt aquick method to characterise the biogas potential of the OFMSW arriving daily at their plant, like a routine analysis.

Keywords

Organic Fraction Municipal Solid Waste; Anaerobic Biogas Production; Dinamic Respirometric Index

Introduction

In newly entered countries in the European Union, the food waste in the municipal solid waste (MSW) represents a significant percentage (Eurostat,2013). The European Council Directive on landfilling of waste (Directive 1999/31/EEC) requires member states to reduce the amount of biodegradable MSW (BMSW) in landfills, over a 15-year period, to 35% of the amount produced in 1995. Thanks to this legislation, new strategies for BMSW treatment for volume reduction, reutilization or energy recovery are and must be developed. The European Directive 2001/77/EC concerning the increase in the use of renewable energy sources in electricity production, was implemented through the D.Lgs.387/2003. Moreover, Italy has set itself the target in 2020 to produce 17% of the total energy consumption from renewable sources and to replace 10% of energy sources designed to transport.

One of the simple and most used methods for biomass energy recovery is represented by anaerobic digestion with biogas generation(NallathambiGunaseelan et al., 1997; Anderottola et al., 2000; Cecchi et al., 2011). The enhancement of OFMSW in anaerobic digestion plants allows a significant reduction of disposal costs, as well as a strong reduction of environmental pollution by allowing parallel revenue from the sale of electricity and thermal energy produced. The composition of the OFMSW is extremely heterogeneous, and depends on many factors such as seasonality, geographical location of the reference basin, the eating habits of the population.For example, in other studies(Hendriks et al., 2009), it is shown that in the summer, when the percentages of MSW green waste increases(coming from mowing garden and public green areas), the yields in ABP of plants treating MSW are drastically reduced, and there is also a reduction of volatile substance. The cause of the decrease in productivity is connected with the increase of the lignin and cellulose content in the treated substrate (Schievano et al., 2010). In the literature, the normal yield of the OFMSW into biogas is approximately 130 Nm^3/t(Murphy et al., 2006; Piccinini et al., 2007). In Italy, the Italian Consortium

of Composters (CIC) hasproposed thata ABP range is between 90-130 Nm^3/t(Giacetti el al.,2011).

Anaerobic digestion plants operators have often to choose which biomasses to use, depending on their digestibility and economical convenience. In this context, rapid methods toassess potential biogas productions are needed. Anaerobic bio-gasification potential (ABP) tests are reliable, but their response times (from 21days for the partial biogas production to 100 days for the total biogas production) areinadequate(Binner and Zach, 1999; Adani et al.,2001; Hansen et al.,2004). As the availability of organic matrixes on the market use to vary day by day, rapid evaluations of the ABP are needed. In the literature,an indirect and faster method was assumed to evaluated the ABP or OFMSW through a respirometric approach (Scaglia et al.,2010). The result can be considered satisfactory as a compromise between precision and rapidity of the assessment.

The present paperaimedto determine the biogas potential production from OFMSWusing the Dynamic Respirometric Index values determined during the laboratory tests carried out with the AIR-nl method in the engineering laboratories of the University of Trento (Scaglia et al.,2010; Dallago 2002).

Material and Methods

In the year 2011 in Italy, 4.1mil.tons of OFMWS were collected, while in the region of Trentino Alto Adige 107,405 tons (Source: ISPRA 2012). In Figure 1, the OFMSW used for the development of the research is presented. The final sample was obtained mixing about three domestic sample of OFMSW collected from the town of Trento.

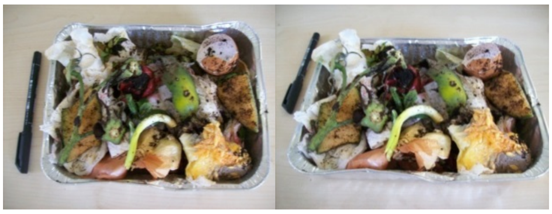


FIGURE 1: SAMPLES OF OFMSW

The ABP is an important parameter; from the comparison of this data for different biomass, it is possible to understand better which are the most productive in biogas generation. Furthermore, it is important to know not only the quantity of biogas production but also the production speed, and the biodegradability of the substrate. The rate of biodegradation is important to know the times when ABP will actually be developed. This is made possible by considering the dynamic respirometric index (DRI), which provides information on the oxygen consumption speed of the organic substance which forms the biomass. The equation that permits to determine the anaerobic biogas potential from the value of dynamic respirometric index is (Scaglia 2010):

$$ABP = (34.4 \pm 2.5) + (0.109 \pm 0.003)DRI \qquad (1)$$

inwhich the ABP and DRI are expressed as Nl kg DM-1 and mg O_2 kg $_{DM}^{-1}$ h^{-1}, respectively. It was developed from RICICLA Group Di.Pro.Ve of the University of Milan, through studies of 46 samples coming directly from MBT full-scale plants.

It is useful to do a regression on the various methodologies present in Italy for the determination of DRI, to better understand what value to use in the relationship for the calculation of ABP. In Italy, the sector of respirometry applied to solid waste is characterized by the adoption of dynamic approaches, and above all there are two different methodologies developed in Italy. In general, the dynamic method to which the Italian regulations refer is the Costech one, developed by Di.Pro.Ve (University of Milan). Parallel to this approach, in the University of Trento, another system for measuring the dynamic respirability of a substrate, the AIR-nlrespirometer, has been developed.

The *AIR-nlrespirometer* is an adiabatic reactor having one probe for temperature and one probe for oxygen measurements. The reactor is kept at the chosen temperature by a thermostatic bath (30°C). The system of aeration and analysis is composed ofa double pneumatic circuit; for this reason the aeration is semi-continuous. In the first one, at low flow, the oxygen concentration is measured in continuous, (always higher than 18.5% (v/v)) (Andreottola et al.,2005); indeed the second one, at higher flow, guarantees the re-oxygenation by a continuous flow of air through the sample. An hourly dynamic respirometric index is assessed in mg_{O2} kg_{vs}^{-1} h^{-1}. Moisture in the sample is corrected to 55% before the test, and 1kg of sample is used for the test.

Regarding to the value of DRI better to use the value of DRI_{24};it is determinated as the average integral over a period of 24 hours during the peak of maximum consumption in terms of oxygen. DRI_{24} is less affected by any peak oxygen consumption of limited duration in the highlighted respirometric path(Dallago 2002). For these reasons, it is recommended to use the value of IRD_{24} to determinate the Potential Production of Biogas, because in this case the value that will be obtained is less sensitiveto error.

Given that the equation (1) uses the $DRI_{Di.Pro.Ve}$, in order to use the values obtained from the Trento method, the University of Trento has madeseveral experimental tests with both methods to find a relationship that makes it possible to compare the two DRI. The main difference between the two methods is in control of the temperature during the test. In the method developed by the group RECICLA,this is not expected.Regarding data recorded with the CostechRespirometer, it was needed to report oxygen consumption to the reference temperature of 30°C,in order to compare the values with theones from the Air-nlrespirometer. In literature, an expression has been proposed valid in the range between 20 and 40°C (Rada et al.,2012):

$$DRI_{30°C} = DRI_T \vartheta^{(30°C-T)} \qquad (2)$$

where T refers to instantaneous temperature at which the measure is done (with the temperature probe placed into the substrate) and ϑ is reference constant, equal to 1.08.

From these studies(Rada et al.,2012) another relationship of first approximation without taking into account the role of the temperature has been made available, which allows correlating the two values of DRI_{24}.

$$DRI_{24\,Costech} = 0.7086\, DRI_{24\,AIR-nl} \qquad (3)$$

This equation shows that the method Di.Pro.Ve underestimates the oxygen consumption, compared to that measured with the method AIR-nl, moreover, the role of temperature is another important parameter to be taken into consideration: the method AIR-nl is based on the concept of constant temperature during the test, unlike the Di.Pro.Ve where the temperature is not adjusted.

Experimental Setup: AIR-nl

The adopted reactor was developed ina PhD thesis at the University of Trento, Italy. The project was based on a typical respirometer for sludge, in which a probe monitors the progressive decrease of present oxygen from a maximum value near saturation to a minimum set value, chosen for preventing limiting conditions. When it reaches its inferior value, a small compressor starts automatically to re-circulate the air and establishes the initial oxygen value in order for the process to be repeated. In this way, the oxygen variations curve permits obtaining a detailed respirometerdiagram which is not limited in time. During the respirometric experiments, the temperature and the volumetric percent of oxygen in the air present in the system are continuously monitored. The aim of the respirometric test is to measure the respirometric activity by a quantity named dynamic respirometric index (DRI), which measures the O_2 consumption rate by the organic fraction decomposing bacteria. This index is expressed as function of time and represents the value of specific respirometric activity $mg_{O2}\, kg_{VS}^{-1}\, h^{-1}$ (Dallago 2002) .

$$DRI = \frac{P*V}{R} * 32 * 1000 * \left(\frac{\%O_{21}}{T_1} - \frac{\%O_{22}}{T_2}\right) * \frac{1}{SV} * \frac{1}{\Delta t} \qquad (4)$$

where p: pressure [atm] equal to the atmospheric one; V: free volume expressed in liters; 32 is the molecular mass of oxygen [g]; VS: is the volatile solids content [kg]; Δt: time [h]; R=0,0821 l atm $mole^{-1}K^{-1}$: perfect gases constant; 1 and 2 indicate the points where the calculus was performed.

To estimate the DRI value,it is necessary to know some physical characteristics of the sample such as moisture, density ans VS.To calculate the moisture of the sample of OFMSW, the Moisture Analyzer HR83 has been usedto determine the moisture content of almost any substance. The instrument works on the thermogravimetric principle: at the start of the measurement the Moisture Analyzerdetermines the weight of the sample which is then quickly heated by the integral halogen heating moduleand the moisture vaporizes. During the drying process, the instrument continually measures the weight of thesample and displays the reduction in moisture. Once drying has been completed, the moisture or solids contentof the sample is displayed as the final result.For the determination of VS, a furnace,model L9/11/SW was used. The difference between the initial total mass and the combustion residue is the combustion loss. During the process, the software includes records both the temperature and the weight loss.Finally, to calculate the density, the methodology ERRA (European Recovery & Recycling Association 1993) has been applied. It is one of the methodologies at European level for characterizein quantitatively and qualitatively MSW.

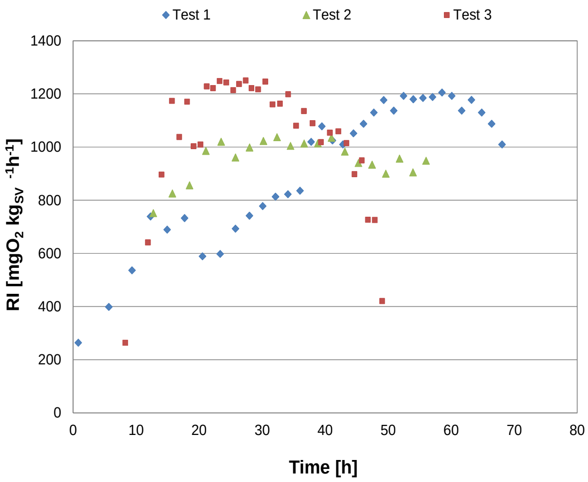
Results

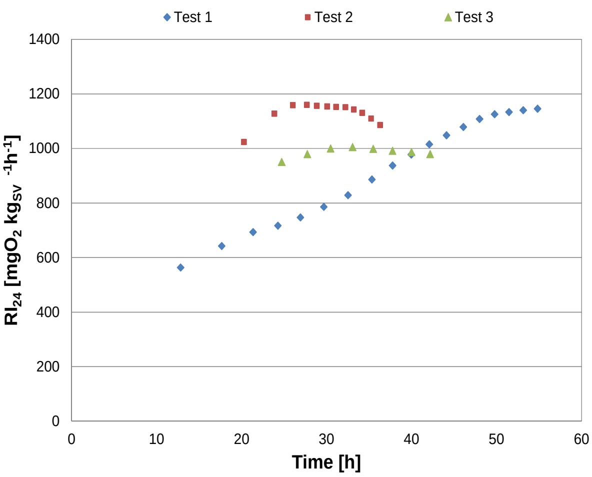
The physical characteristics of the treated sampleare presented in Table 1.These values were determined by measurement in the laboratories of the University of Trento.

TABLE 1: PHYSICAL CHARACTERISTICS OF THE SAMPLES

Samples	Moisture	Density	VS
	[%]	[kg/l]	[%]
OFMSW	60.42	0.75	75

In the present paper, one sample of organic fraction of municipal solid waste (OFMSW) collected in Trento was analysed. Three respirometric tests were performed for better emphasizing the obtained results, due to the heterogeneity of the materials. The results for the DRI and DRI_{24} variation are shown in Figure 2.





a) Food waste DRI variation b) Food wasteDRI24 variation

FIGURE 2. ORGANIC MSW RESPIROMETRIC VARIATION

The available measurements and calculation results are presented in Table 2.

TABLE 2: RESULTS ABOUT AIR-NL OF OFMSW SAMPLE

Weight	Time	DRI	DRI_{24}	DRI_{med}	DRI_{24med}
[kg]	[h]	$[mg_{O2}kg_{vs}^{-1}h^{-1}]$		$[mg_{O2}kg_{vs}^{-1}h^{-1}]$	
1.04	56.01	1,036.71	1,004.96		
0.93	49.04	1,250	1,159.51	1,164.99	1,103.34
0.98	68.07	1,208.28	1,145.56		

The OFMSW is composed ofdifferent types of biodegradable wastes present in the household waste. Normally, the value of DRI for food waste is around 2000-4000$mg_{O2}kgvs^{-1}h^{-1}$(Scaglia et al.,2008). The differences which appear for the test performed on the same type of sample are caused by the heterogeneous character of the OFMSW. A reason for this difference in the expected value, may be given by the period in which the sample of OFMSW was collected. Samples were collected in winter, when the content of the putrescible fraction in OFMSW is very small, because the householders eat less vegetables than that at the summer or spring time. For this reason, other values were selected for use from other studies made by the University of Trento on other samples of OFMSW.

Through the relationship (2) and (3) seen in the previous paragraph, it was determined that, from $DRI_{24\ AIR\text{-}nl}$ values, an average value of $DRI_{24Costech}$is equal to 3,805mg_{O2} kg_{vs}^{-1} h^{-1}.

TABLE 3: RESULTS ABOUT AIR-NL AND COSTECH METHOD

Sam	DRI_{24}AIR-nl	Aver.Temp.	DRI24 (ref. T: Costech)	DRI_{24}Costech	AverageTemp.
	[mgO_2 kg VS^{-1} h^{-1}]	[°C]	[mgO_2 kg VS^{-1} h^{-1}]	[mgO_2 kg VS^{-1} h^{-1}]	[°C]
1	2,754	31.1	5,256	3,724	39.5
2	2,824	30.4	5,474	3,878	39.0
3	2,735	30.4	5,383	3,814	39.2

This value is consistent with other characteristic values of this matrix obtained by other studies (Scaglia et al.,2008). The values of the potential production of biogas (ABP) of such samples of OFMSW analyzed are reported in the following Table 4, determined by the equation (1).

TABLE 4: VALUES OF ABP FOR OFSMW SAMPLES

Sample	ABPmax	ABPmin	ABPmax	ABPmin
	[Nm^3/t VS]	[Nm^3/t VS]	[Nm^3/t_{in}]	[Nm^3 /$t_{in.}$]
OFMSW	475.45	445.95	*141.12*	*132.36*

ThisOFMSW shows a high degree of putrescibility and moisture (greater than 60%) that makes them suitable to anaerobic digestion. The application of anaerobic digestion to waste treatment allows both to produce, through the aerobic treatment of the digested sludge, a residue stabilized employable as organic fertilizer in agriculture, and to achieve a considerable energy recovery, through the use of biogas produced. The appearance of the energy recovery is undoubtedly the most interesting. The biogas produced consistsmostly of methane (50-75%, but normally the value of CH_4 is 60%) (Sosnowski et al., 2003),it has a high calorific value (approximately of 5.5 kWh/Nm^3) (source: ENAMA) and therefore it can be conveniently converted to almost all forms of useful energy: heat, electricity and cogeneration.From the statistical data obtained from the portal of the province of Trento, it is seen that the amount of OFMSW from separate collection of municipal waste is equal to 47,098 tons for the year 2011 (STATweb, 2013). From studies in the

literature(Piccinini et al.,2008), it appears that by the treatment of the biogas cogeneration the following quantities of electricity and thermal energy from 1 $m^3$of biogas can be obtained: from 1.8 to 2 kWh of electricity energy, and 2-3 kWh of heat thermal energy. If all the OFMSW produced inProvince of Trentoin 2011 wereaddressed to the formation of biogas, it would be possible to obtain 12,236 MWhel and 16,083 MWht, as presented in the Table 5 and Table 6.

TABLE 5: VALUES OF BIOGAS PRODUCTION

Samp.	Prod.	ABP_{ave}	Biogas Prod.
	[Tons]	[Nm^3/t]	[Nm^3]
OFMSW	47,098	136.7	6,440,180.2

TABLE 6: VALUES OF ELECTRICITY AND THERMAL ENERGY PRODUCTION

Samp.	Biogas Prod.	Electricity Prod.	Thermal Prod.
	[Nm^3]	[MWhel.]	[MWht.]
OFMSW	6,440,180.2	12,236.3	16,083.9

Conclusions

During this study, it emerged that the relation between the values of ABP and the DRI is a useful method to determine in a short time the value of the potential production of biogas in the case of OFMSW. Moreover, as the composition of the organic matrix varies in both geographically and seasonally, rapid methods to determine the potential in biogas are needed. Through this report, the waiting time to obtain this information is shorter. It passes from 21-60 days to just 1-4 days, time needed to conduct a respirometric test.In this way,it may be possible for the plant operators to use this method to value the OFMSW more productive into biogas production that arrive daily at the plant, like a routine analysis.

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